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Sumiyoshi

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(54) **IMAGE CORRECTION SYSTEM, IMAGE CORRECTION METHOD, AND COMPUTER PROGRAM PRODUCT**

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(73) Assignee: **RICOH COMPANY, LIMITED**, Tokyo (JP)

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Sep. 17, 2013 (JP) 2013-192385

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G06K 9/46 (2006.01)
G06T 5/00 (2006.01)
(Continued)

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CPC ***G06T 5/006*** (2013.01); ***G06K 9/52*** (2013.01); ***G06T 3/00*** (2013.01); ***G06T 3/60*** (2013.01);
(Continued)

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CPC G06K 9/52; G06T 3/00; G06T 3/60; G06T 5/006; G09G 2360/147; G09G 3/001; H04N 5/217; H04N 5/23229; H04N 5/23258; H04N 9/3185; H04N 9/3194
USPC 382/203
See application file for complete search history.

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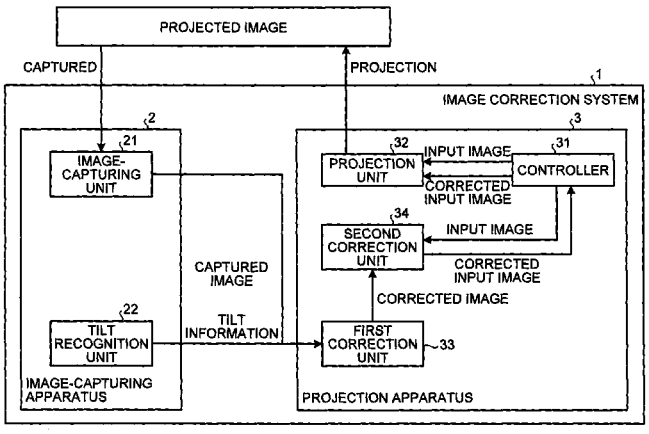
(74) *Attorney, Agent, or Firm* — Oblon, McClelland, Maier & Neustadt, L.L.P.

(57) **ABSTRACT**

This invention is concerning an image correction system that includes an image-capturing unit configured to acquire a captured image by capturing a subject; a tilt recognition unit configured to recognize tilt of an image-capturing direction of the image-capturing unit relative to an image-capturing direction in which the image-capturing unit being directly opposite to the subject captures the subject; a first correction unit configured to generate a corrected image by correcting distortion in the captured image due to the tilt; and a second correction unit configured to acquire a corrected captured image by correcting non-linear distortion in the corrected image.

7 Claims, 17 Drawing Sheets



(51) **Int. Cl.**

G09G 3/00	(2006.01)
H04N 9/31	(2006.01)
G06K 9/52	(2006.01)
G06T 3/00	(2006.01)
G06T 3/60	(2006.01)
H04N 5/232	(2006.01)
H04N 5/217	(2011.01)

(52) **U.S. Cl.**

CPC ***G09G 3/001*** (2013.01); ***H04N 5/217*** (2013.01); ***H04N 5/23229*** (2013.01); ***H04N 9/3185*** (2013.01); ***H04N 9/3194*** (2013.01); *G09G 2360/147* (2013.01); *H04N 5/23258* (2013.01)

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FIG.1

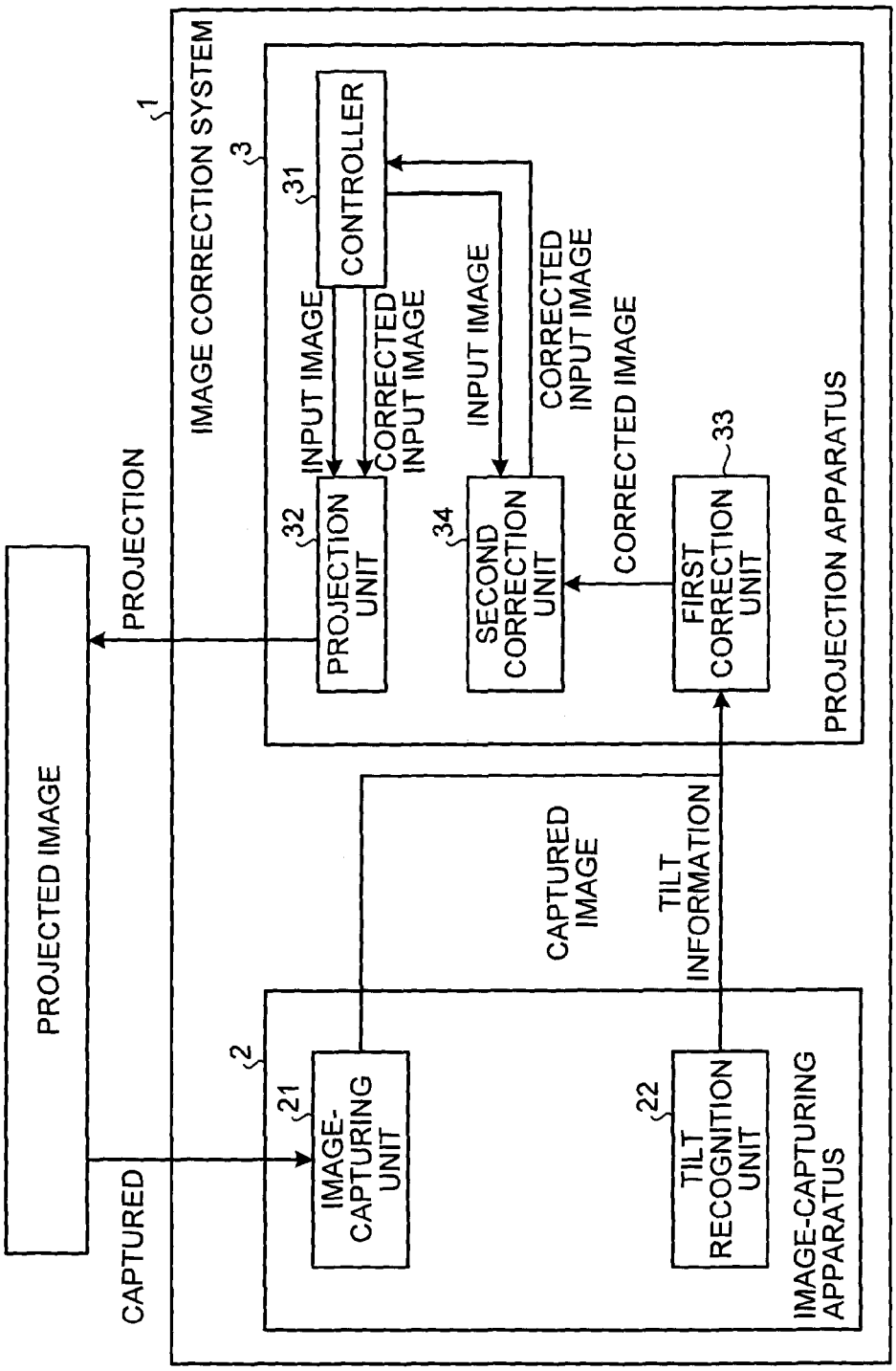


IMAGE CORRECTION SYSTEM
1
PROJECTED IMAGE
PROJECTION
CAPTURED
3
CONTROLLER
31
INPUT IMAGE
CORRECTED INPUT IMAGE
INPUT IMAGE
CORRECTED INPUT IMAGE
CORRECTED IMAGE
32
PROJECTION UNIT
34
SECOND CORRECTION UNIT
33
FIRST CORRECTION UNIT
PROJECTION APPARATUS
CAPTURED IMAGE
TILT INFORMATION
2
21
IMAGE-CAPTURING UNIT
22
TILT RECOGNITION UNIT
IMAGE-CAPTURING APPARATUS

FIG.2

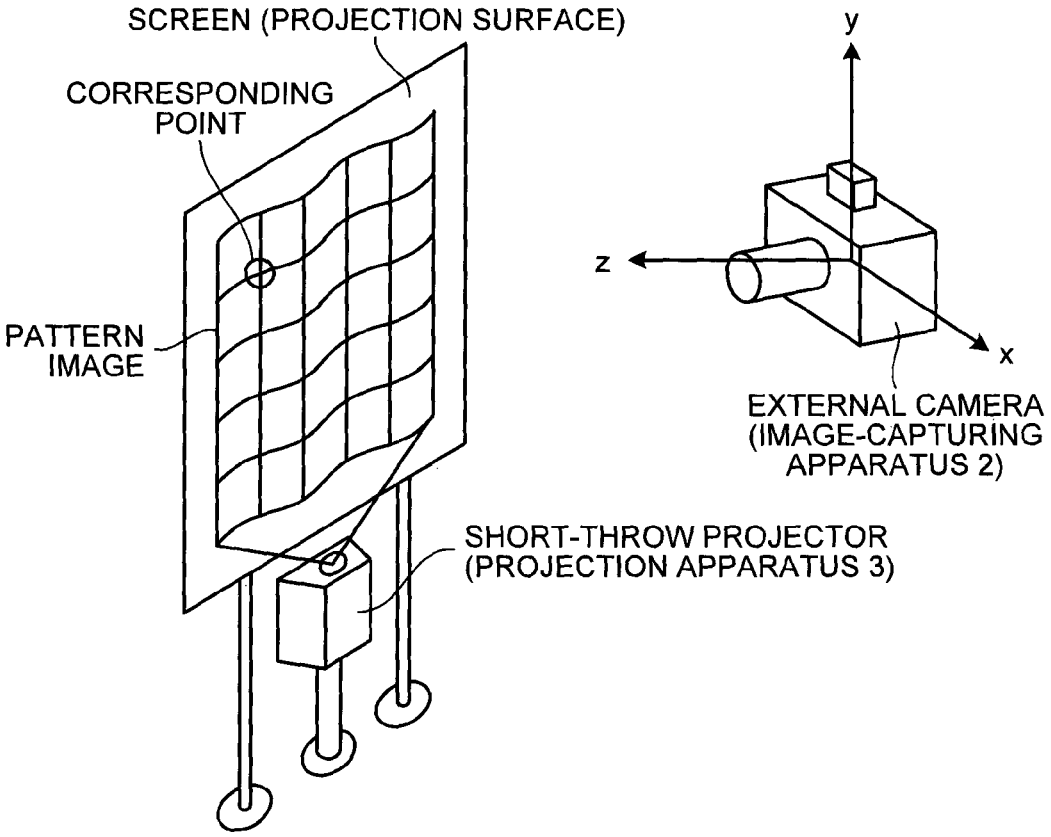
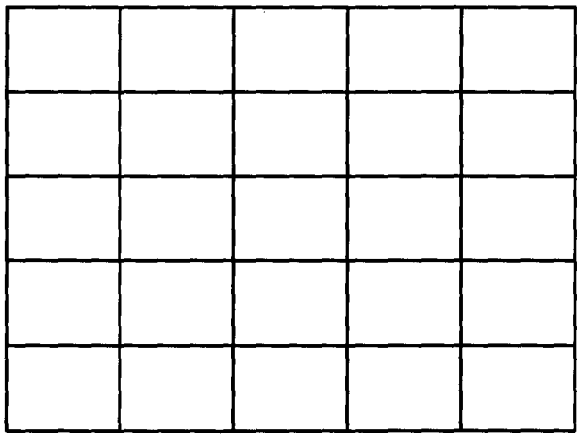


FIG.3



GRID PATTERN IMAGE

FIG.4

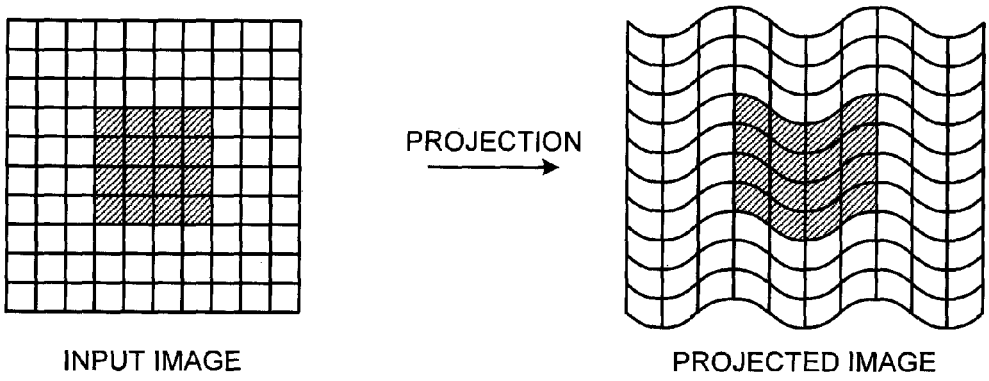

PROJECTION
INPUT IMAGE
PROJECTED IMAGE

FIG.5

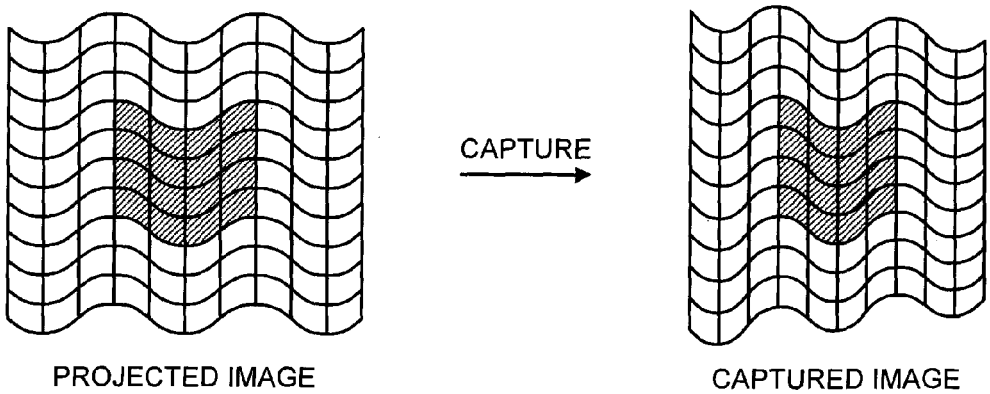

CAPTURE
PROJECTED IMAGE
CAPTURED IMAGE

FIG.6

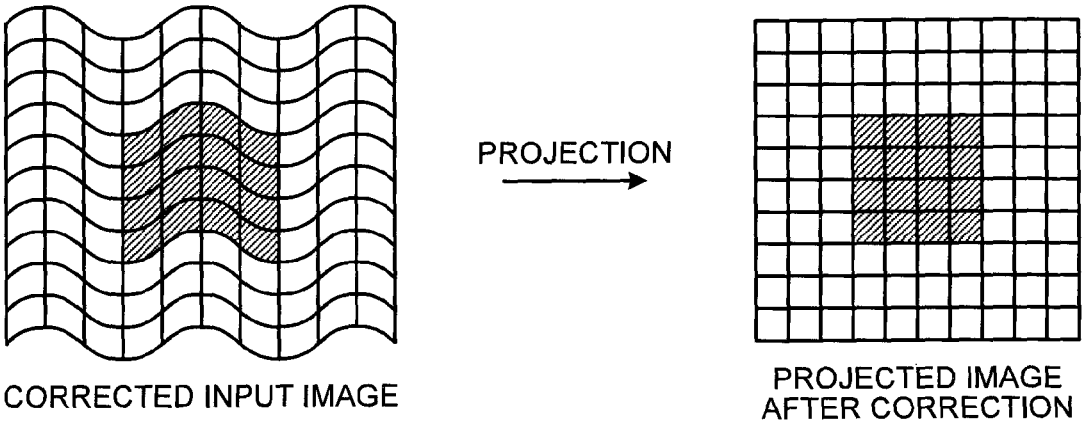

PROJECTION
CORRECTED INPUT IMAGE
PROJECTED IMAGE AFTER CORRECTION

FIG.7

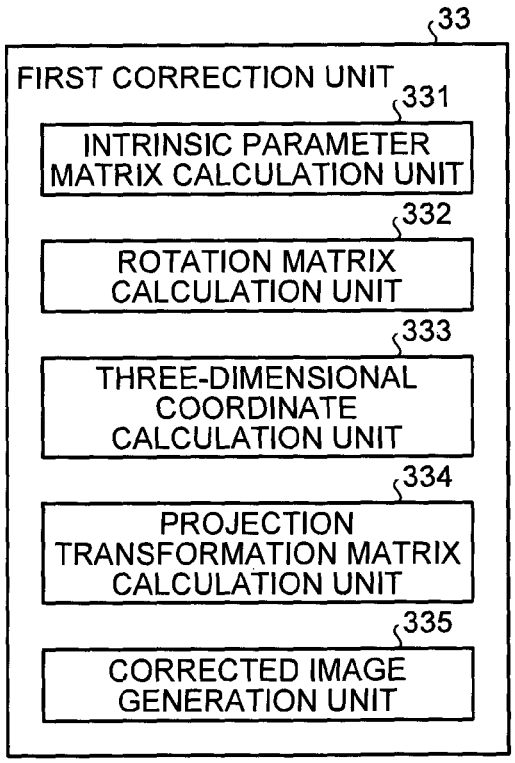

33
FIRST CORRECTION UNIT
331
INTRINSIC PARAMETER MATRIX CALCULATION UNIT
332
ROTATION MATRIX CALCULATION UNIT
333
THREE-DIMENSIONAL COORDINATE CALCULATION UNIT
334
PROJECTION TRANSFORMATION MATRIX CALCULATION UNIT
335
CORRECTED IMAGE GENERATION UNIT

FIG.8

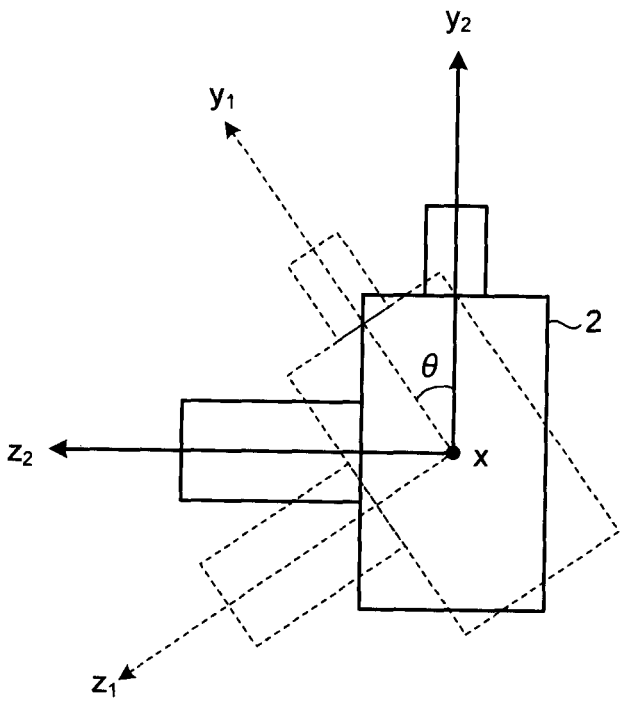


FIG.9

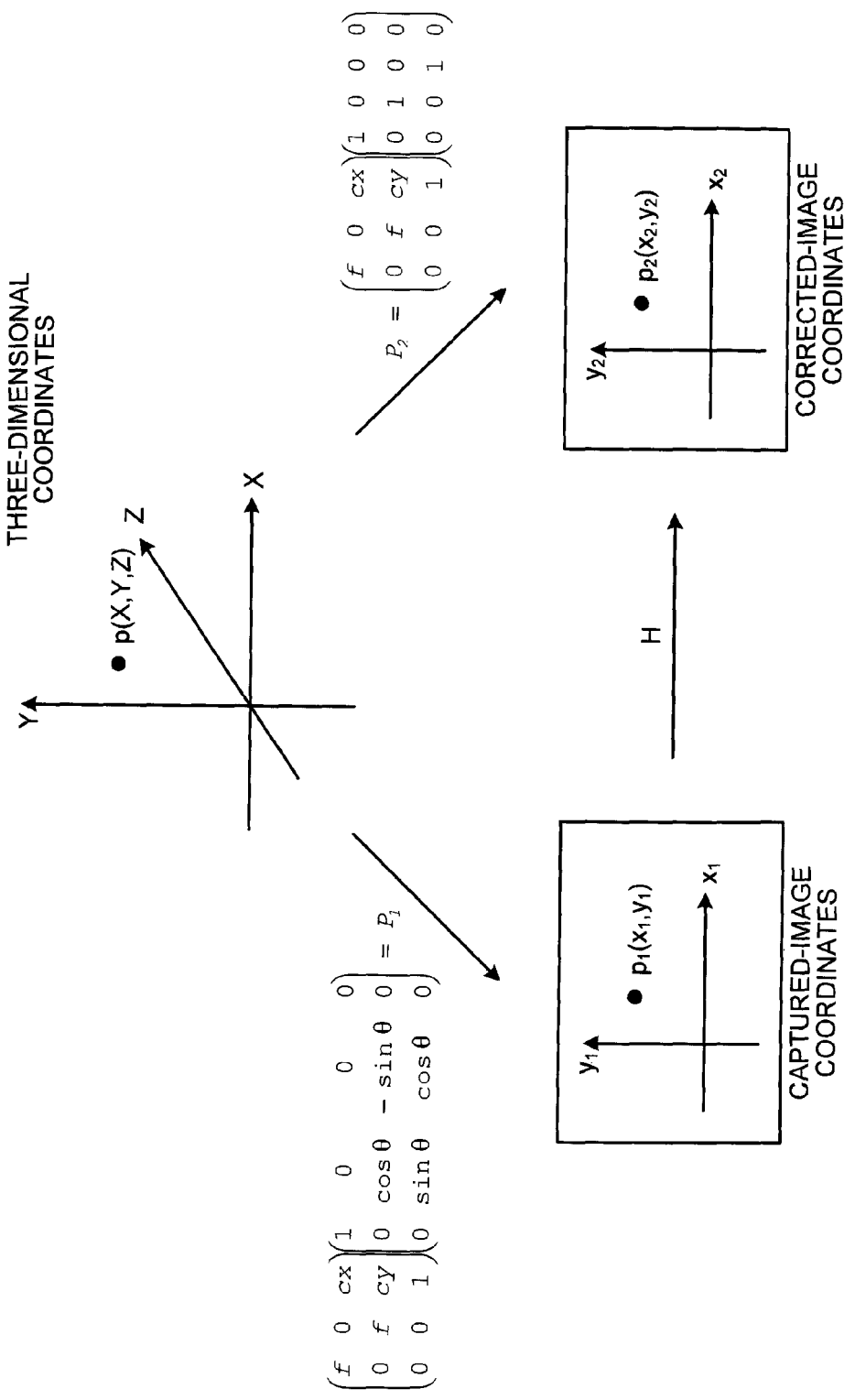

THREE-DIMENSIONAL COORDINATES
p(X,Y,Z)
X
Y
Z
$P_2 = \begin{pmatrix} f & 0 & cx \\ 0 & f & cy \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$
$\begin{pmatrix} f & 0 & cx \\ 0 & f & cy \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \end{pmatrix} = P_1$
H
$p_1(x_1,y_1)$
x_1
y_1
CAPTURED-IMAGE COORDINATES
$p_2(x_2,y_2)$
x_2
y_2
CORRECTED-IMAGE COORDINATES

FIG.10

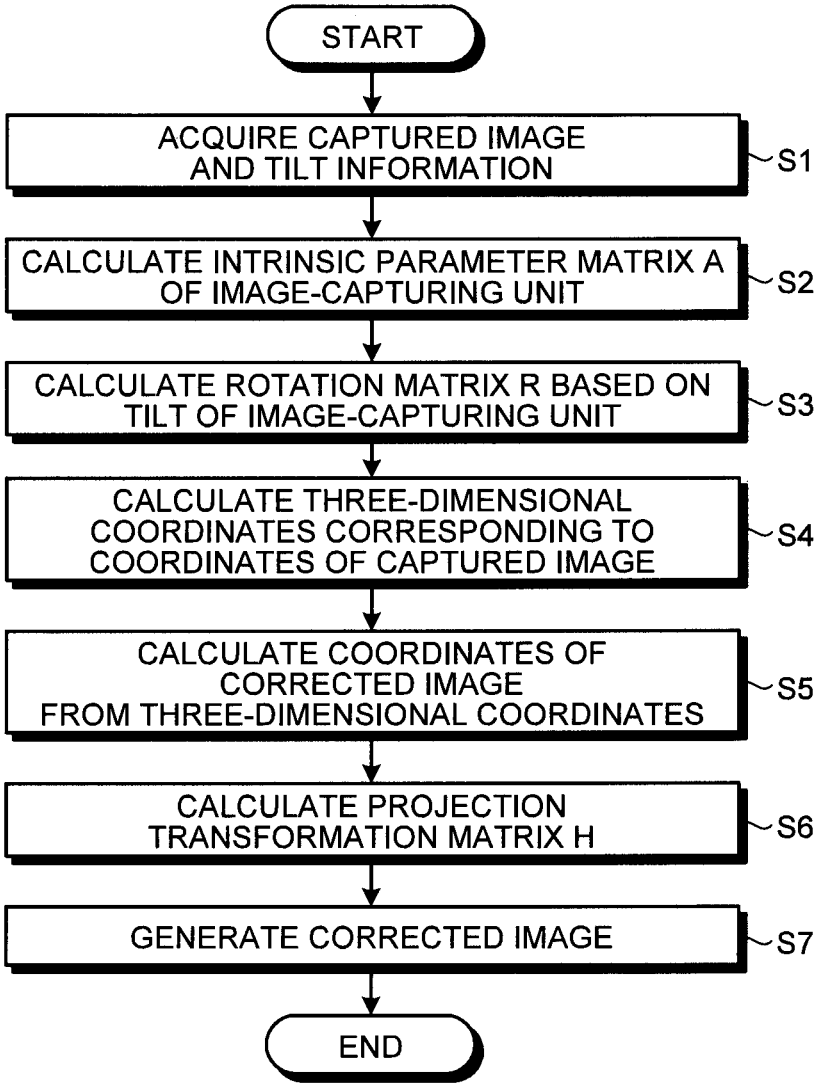

START
ACQUIRE CAPTURED IMAGE AND TILT INFORMATION
S1
CALCULATE INTRINSIC PARAMETER MATRIX A OF IMAGE-CAPTURING UNIT
S2
CALCULATE ROTATION MATRIX R BASED ON TILT OF IMAGE-CAPTURING UNIT
S3
CALCULATE THREE-DIMENSIONAL COORDINATES CORRESPONDING TO COORDINATES OF CAPTURED IMAGE
S4
CALCULATE COORDINATES OF CORRECTED IMAGE FROM THREE-DIMENSIONAL COORDINATES
S5
CALCULATE PROJECTION TRANSFORMATION MATRIX H
S6
GENERATE CORRECTED IMAGE
S7
END

FIG.11

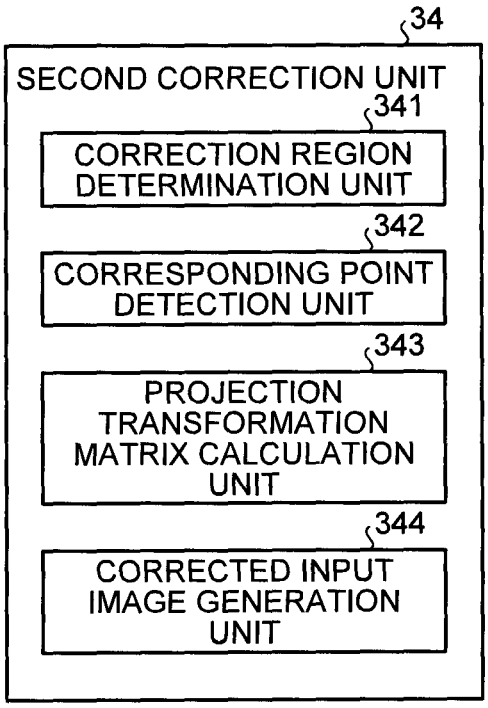

34
SECOND CORRECTION UNIT
341
CORRECTION REGION DETERMINATION UNIT
342
CORRESPONDING POINT DETECTION UNIT
343
PROJECTION TRANSFORMATION MATRIX CALCULATION UNIT
344
CORRECTED INPUT IMAGE GENERATION UNIT

FIG.12

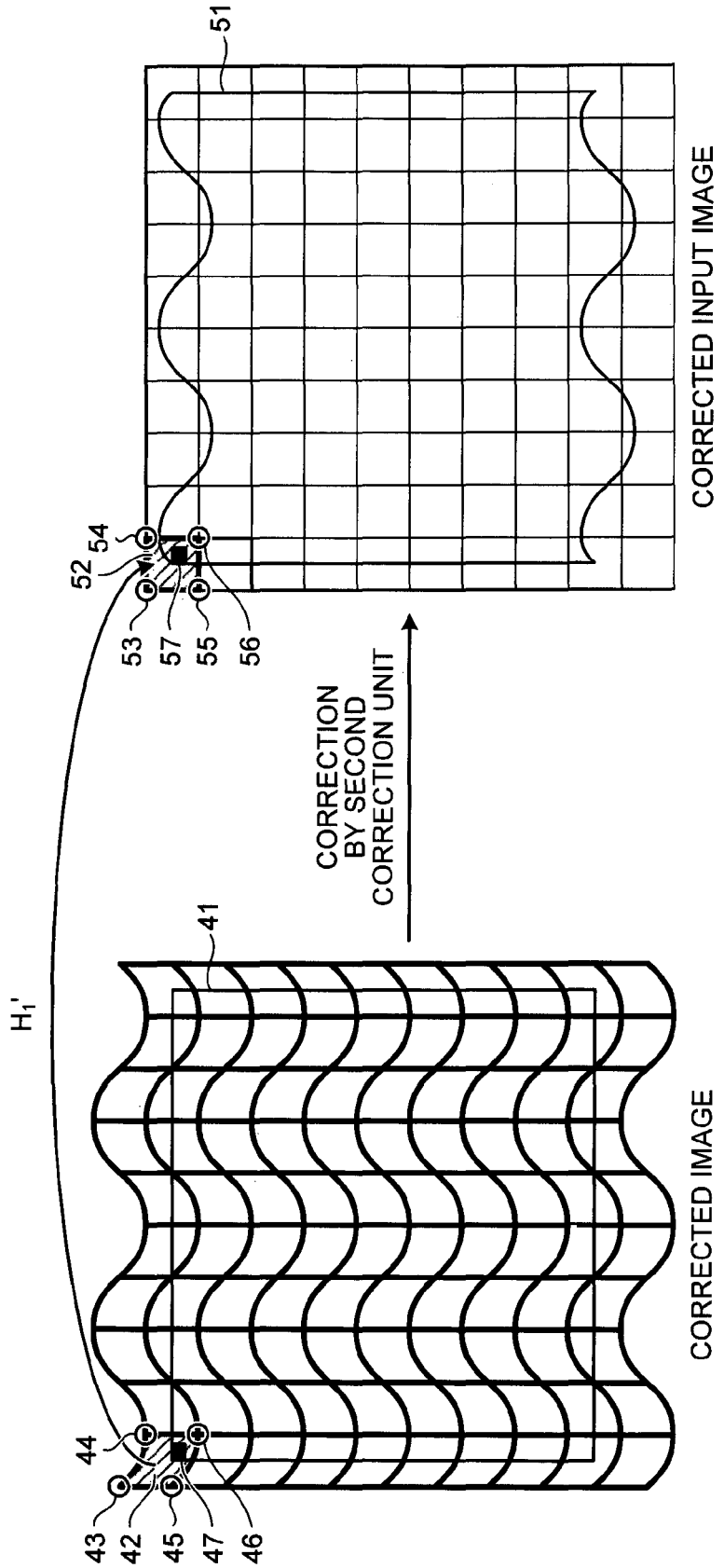

51
CORRECTED INPUT IMAGE
52
54
53
57
55
56
CORRECTION BY SECOND CORRECTION UNIT
H1'
41
CORRECTED IMAGE
44
43
42
45
47
46

FIG.13

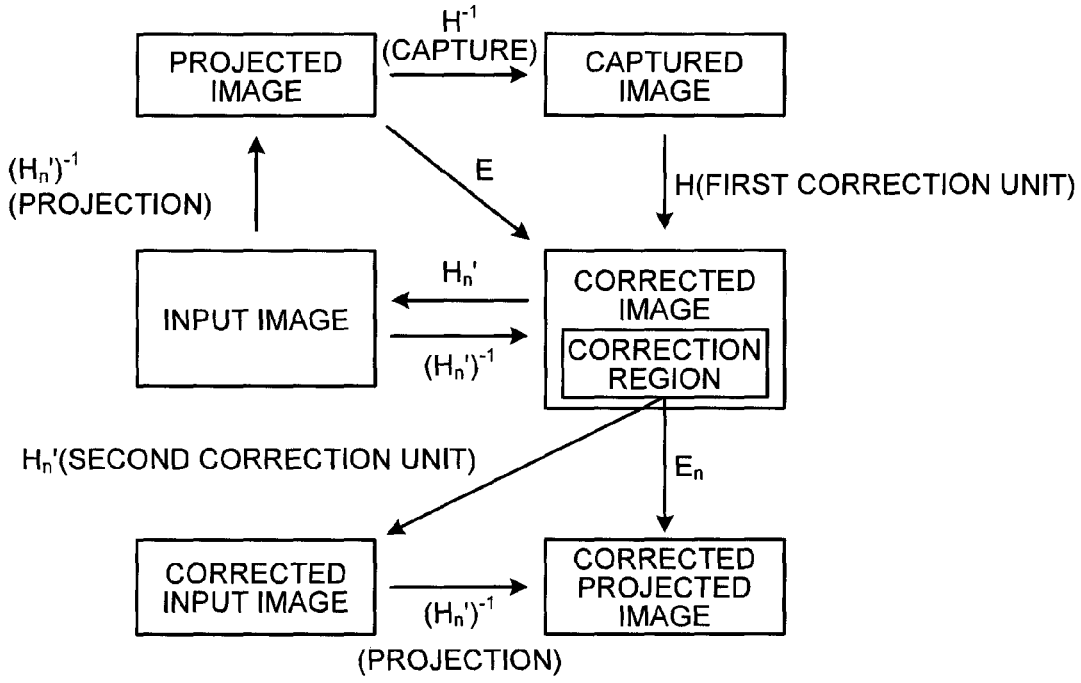

PROJECTED IMAGE
H^{-1} (CAPTURE)
CAPTURED IMAGE
$(H_n')^{-1}$ (PROJECTION)
E
H(FIRST CORRECTION UNIT)
INPUT IMAGE
H_n'
$(H_n')^{-1}$
CORRECTED IMAGE
CORRECTION REGION
H_n'(SECOND CORRECTION UNIT)
E_n
CORRECTED INPUT IMAGE
$(H_n')^{-1}$ (PROJECTION)
CORRECTED PROJECTED IMAGE

FIG.14

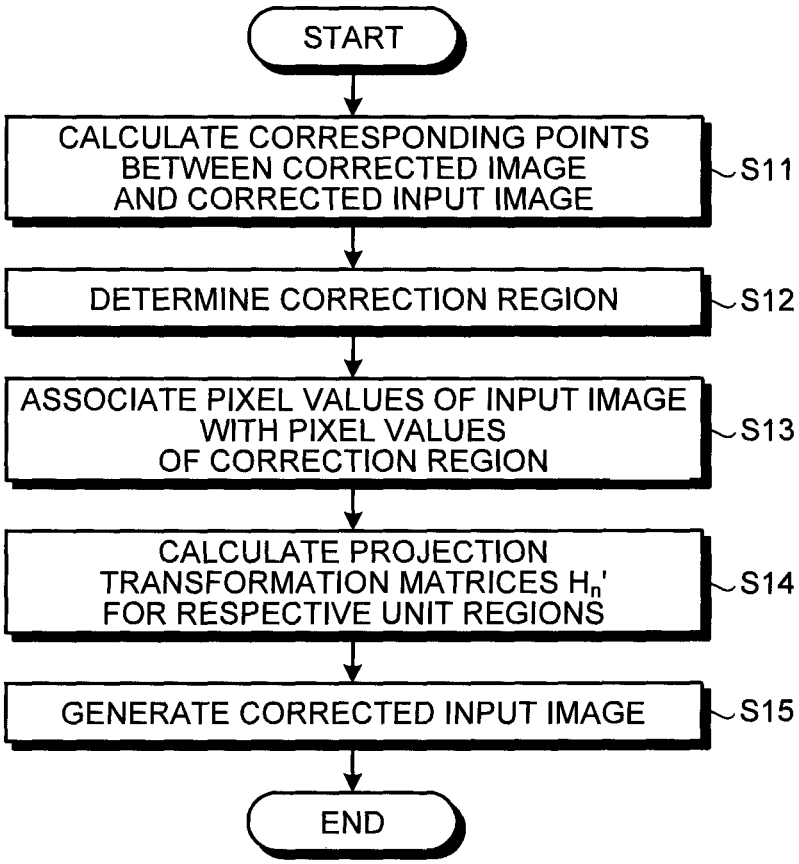

START
CALCULATE CORRESPONDING POINTS BETWEEN CORRECTED IMAGE AND CORRECTED INPUT IMAGE
S11
DETERMINE CORRECTION REGION
S12
ASSOCIATE PIXEL VALUES OF INPUT IMAGE WITH PIXEL VALUES OF CORRECTION REGION
S13
CALCULATE PROJECTION TRANSFORMATION MATRICES H_n' FOR RESPECTIVE UNIT REGIONS
S14
GENERATE CORRECTED INPUT IMAGE
S15
END

FIG.15

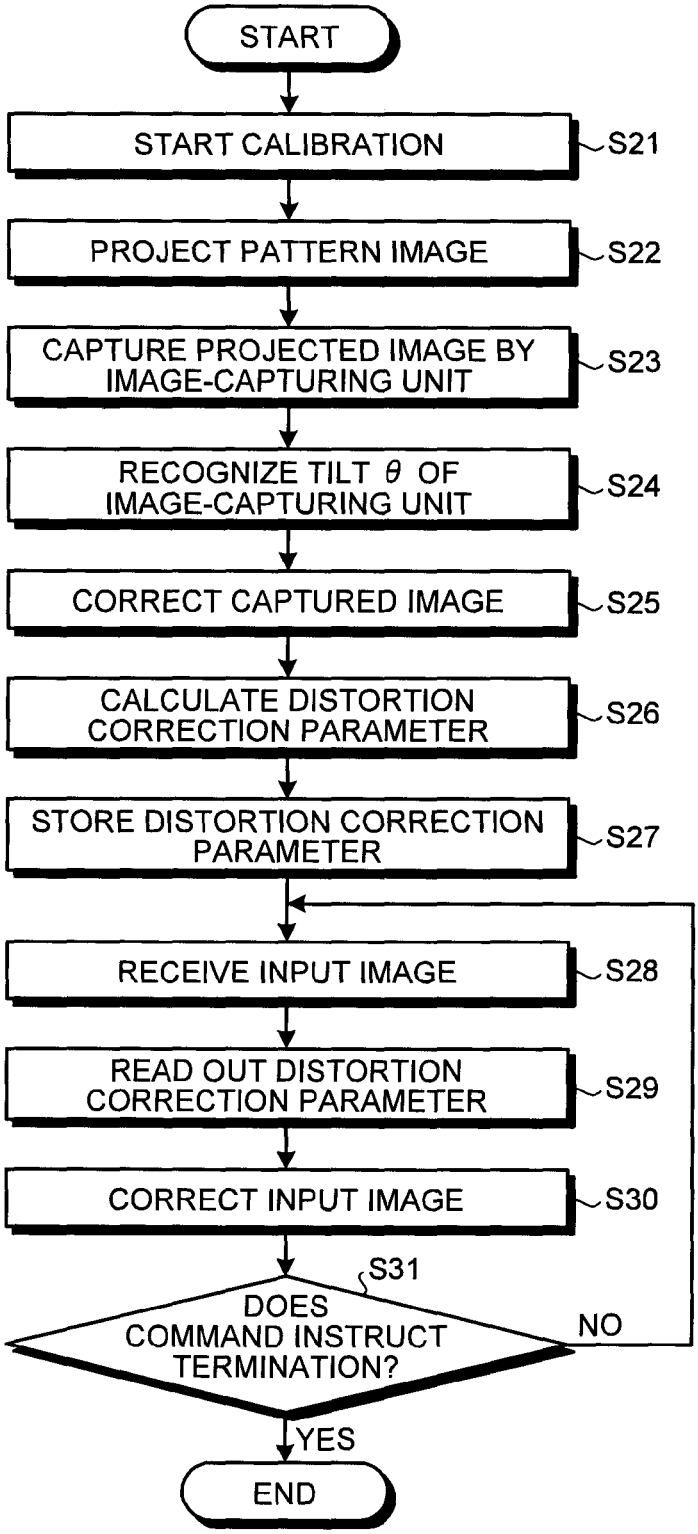

START
START CALIBRATION
S21
PROJECT PATTERN IMAGE
S22
CAPTURE PROJECTED IMAGE BY IMAGE-CAPTURING UNIT
S23
RECOGNIZE TILT θ OF IMAGE-CAPTURING UNIT
S24
CORRECT CAPTURED IMAGE
S25
CALCULATE DISTORTION CORRECTION PARAMETER
S26
STORE DISTORTION CORRECTION PARAMETER
S27
RECEIVE INPUT IMAGE
S28
READ OUT DISTORTION CORRECTION PARAMETER
S29
CORRECT INPUT IMAGE
S30
S31
DOES COMMAND INSTRUCT TERMINATION?
NO
YES
END

FIG.16

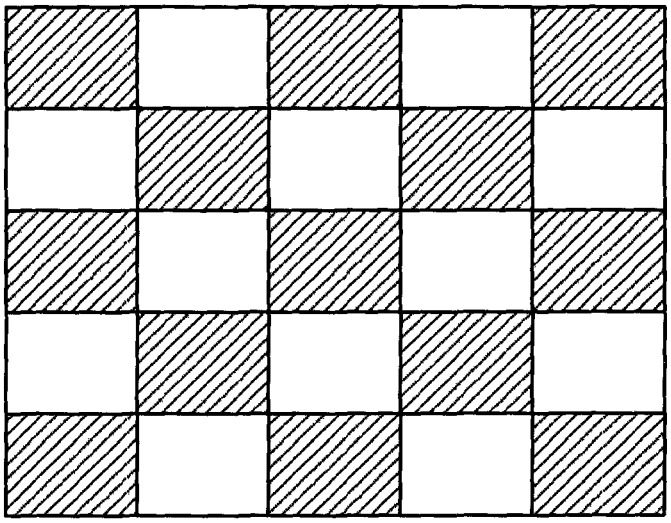


FIG.17

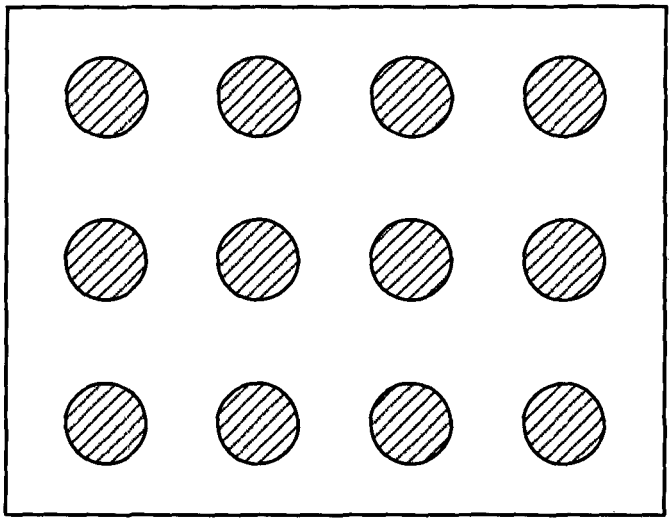


FIG.18

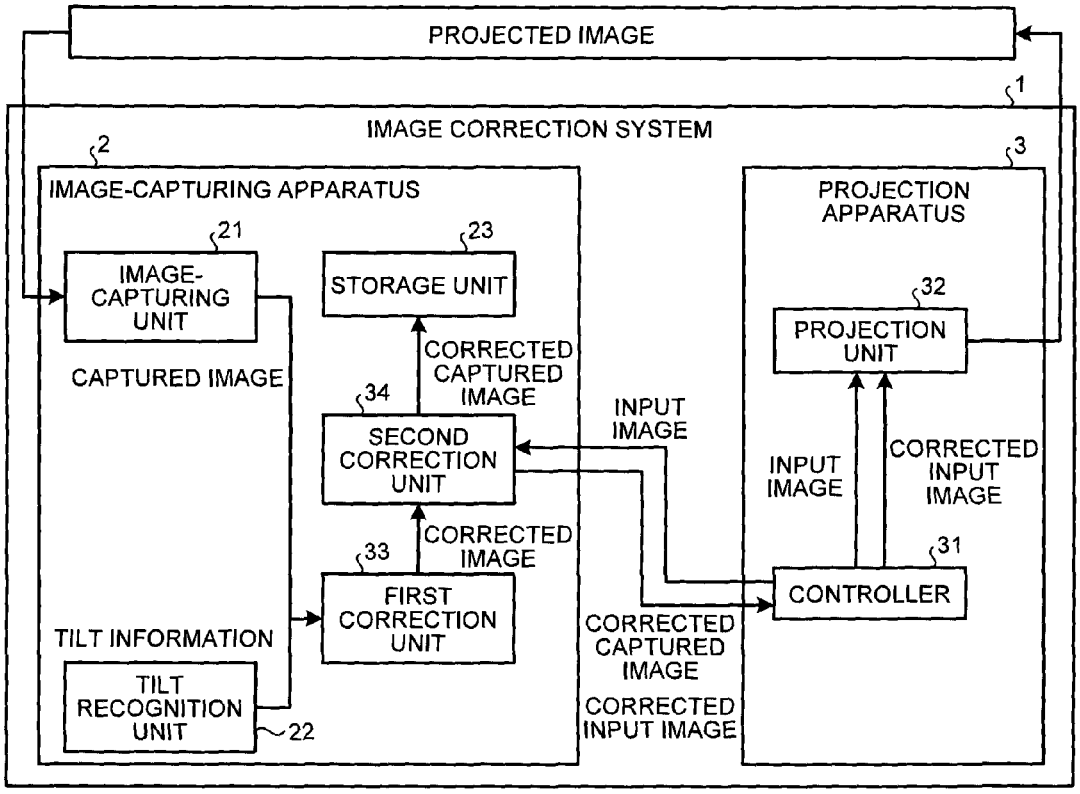

PROJECTED IMAGE
1
IMAGE CORRECTION SYSTEM
2
IMAGE-CAPTURING APPARATUS
21
IMAGE-CAPTURING UNIT
CAPTURED IMAGE
23
STORAGE UNIT
CORRECTED CAPTURED IMAGE
34
SECOND CORRECTION UNIT
CORRECTED IMAGE
33
FIRST CORRECTION UNIT
TILT INFORMATION
TILT RECOGNITION UNIT
22
INPUT IMAGE
CORRECTED CAPTURED IMAGE
CORRECTED INPUT IMAGE
3
PROJECTION APPARATUS
32
PROJECTION UNIT
INPUT IMAGE
CORRECTED INPUT IMAGE
31
CONTROLLER

FIG.19

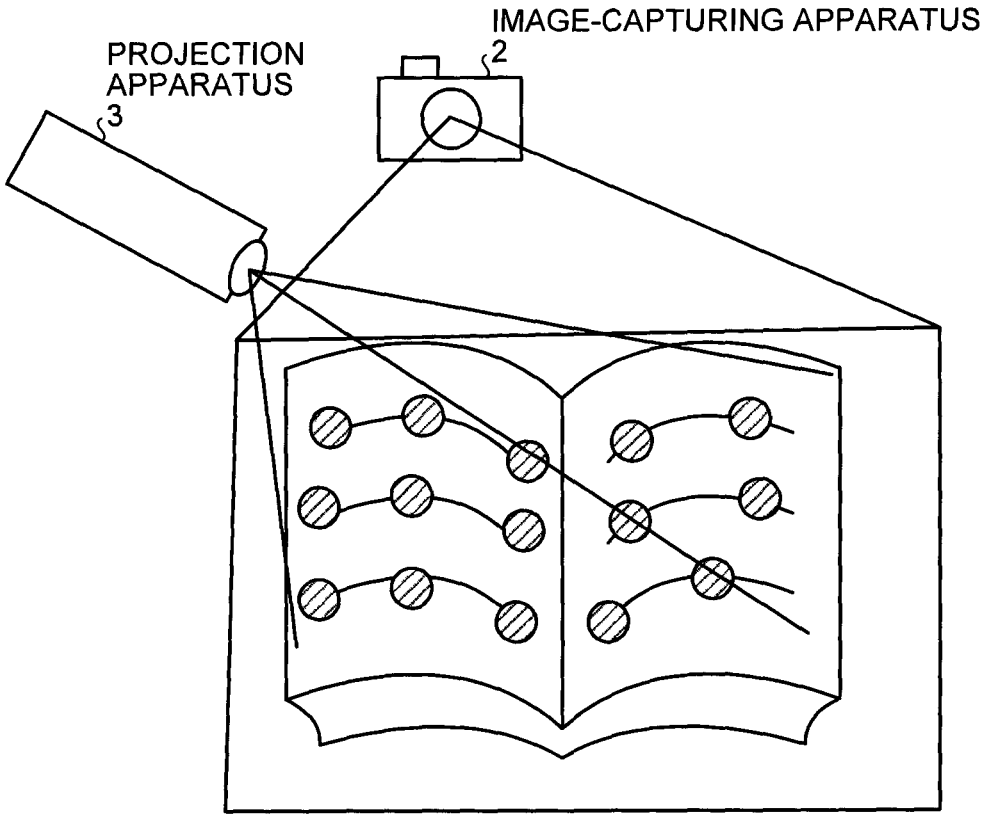


FIG.20

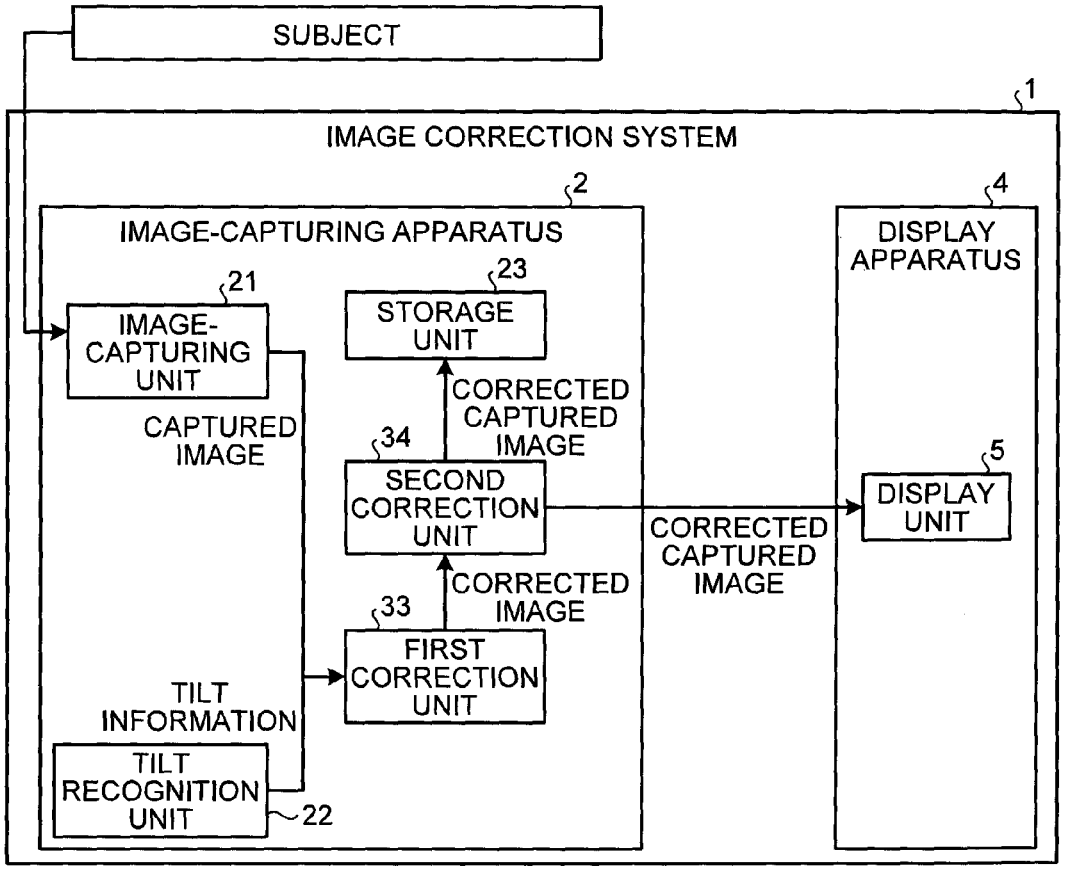

SUBJECT
1
IMAGE CORRECTION SYSTEM
2
IMAGE-CAPTURING APPARATUS
4
DISPLAY APPARATUS
21
IMAGE-CAPTURING UNIT
23
STORAGE UNIT
CAPTURED IMAGE
CORRECTED CAPTURED IMAGE
34
SECOND CORRECTION UNIT
5
DISPLAY UNIT
CORRECTED CAPTURED IMAGE
CORRECTED IMAGE
33
FIRST CORRECTION UNIT
TILT INFORMATION
TILT RECOGNITION UNIT
22

FIG.21

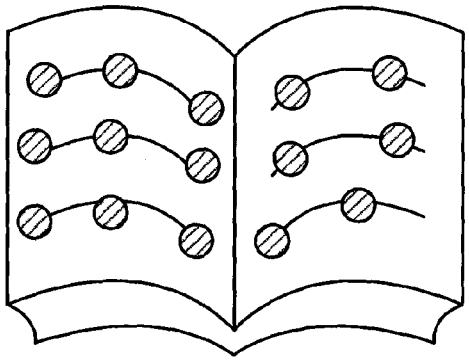


FIG.22

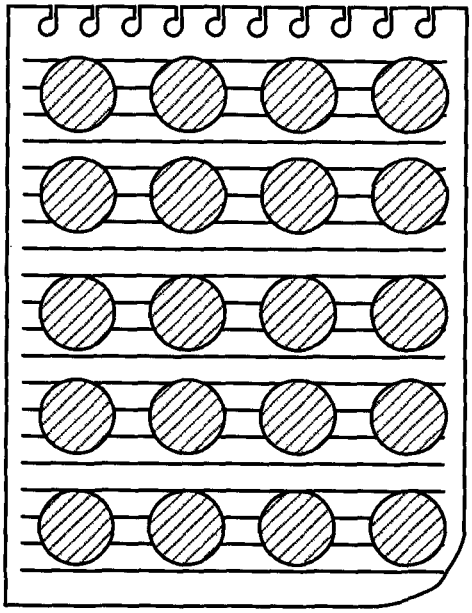


FIG.23

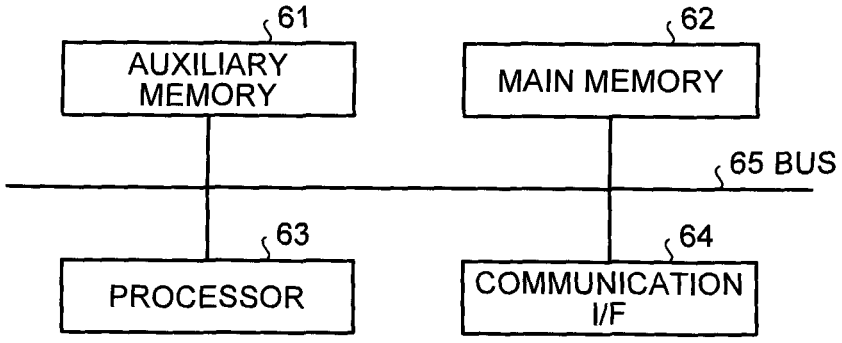

61
AUXILIARY MEMORY
62
MAIN MEMORY
65 BUS
63
PROCESSOR
64
COMMUNICATION I/F

IMAGE CORRECTION SYSTEM, IMAGE CORRECTION METHOD, AND COMPUTER PROGRAM PRODUCT

TECHNICAL FIELD

The present invention relates to an image correction system, an image correction method, and a computer program product.

BACKGROUND ART

It is known that there are two types of distortion, linear distortion (trapezoidal distortion) and non-linear distortion, that can occur in a projected image projected by a projection apparatus such as a projector. Linear distortion occurs, for example, when the projection apparatus deviates from a position directly opposite to a projection surface. In other words, linear distortion occurs when a projection apparatus designed to be disposed in a position perpendicular to a projection surface is not directly opposite to the projection surface.

Non-linear distortion occurs, for example, when a projection surface such as a hanging projector screen is uneven. In general, an uneven projection surface such as a hanging projector screen lacks linearity, thus non-linear distortion occurs.

A projection system (projector and camera system) that includes a projection apparatus and an image-capturing apparatus is a well-known technology to correct distortion in a projected image. For example, this technology corrects distortion in a projected image projected by the projection apparatus such as a projector on the basis of a captured image captured by a portable image-capturing apparatus (such as a digital camera, a web camera, and a camera built in a mobile phone or a smart phone, and hereinafter referred to as an "external camera").

Patent document 1 is known as a technical document that discloses a technique to correct distortion in a projected image. Patent document 1 discloses an invention to correct distortion in a projected image by using a captured image captured by a mobile phone with a built-in camera.

However, linear distortion occurs in a corrected projected image in some cases when a captured image acquired by an image-capturing apparatus capturing a projected image is used, for example, in order to correct distortion in the projected image due to unevenness of a projection surface.

CITATION LIST

Patent Literature

[Patent Literature 1] Japanese Patent Application Laid-open No. 2006-033357

DISCLOSURE OF INVENTION

Problem to be Solved by the Invention

The present invention has been made in view of the disadvantage described above, and it is an object of the present invention to provide an image correction system, an image correction method and a computer program product with which, if a captured image acquired by an image-capturing apparatus capturing a subject is distorted, distortion of the subject contained in the captured image can be eliminated by utilizing the captured image.

Means for Solving Problem

To achieve the object, an image correction system according to the present invention includes: an image-capturing unit configured to acquire a captured image by capturing a subject; a tilt recognition unit configured to recognize tilt of an image-capturing direction of the image-capturing unit relative to an image-capturing direction in which the image-capturing unit being directly opposite to the subject captures the subject; a first correction unit configured to generate a corrected image by correcting distortion in the captured image due to the tilt; and a second correction unit configured to acquire a corrected captured image by correcting non-linear distortion in the corrected image.

An image correction method according to the present invention comprising: acquiring, by an image-capturing unit, a captured image by capturing a subject; recognizing, by a tilt recognition unit, tilt of an image-capturing direction of the image-capturing unit relative to an image-capturing direction in which the image-capturing unit being directly opposite to the subject captures the subject; generating, by a first correction unit, a corrected image by correcting distortion in the captured image due to the tilt; and acquiring, by a second correction unit, a corrected captured image by correcting non-linear distortion in the corrected image.

A computer program product according to the present invention comprising a non-transitory computer-usable medium having a computer program that causes a computer to function as: an image-capturing unit configured to acquire a captured image by capturing a subject; a tilt recognition unit configured to recognize tilt of an image-capturing direction of the image-capturing unit relative to an image-capturing direction in which the image-capturing unit being directly opposite to the subject captures the subject; a first correction unit configured to generate a corrected image by correcting distortion in the captured image due to the tilt; and a second correction unit configured to acquire a corrected captured image by correcting non-linear distortion in the corrected image.

Effect of the Invention

According to the present invention, if a captured image acquired by an image-capturing apparatus capturing a subject is distorted, the distortion of the subject contained in the captured image can be eliminated by utilizing the captured image.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a block diagram illustrating an example of a configuration of functional blocks in an image correction system according to a first embodiment;

FIG. **2** is a diagram illustrating an example of an embodiment of the image correction system according to the first embodiment;

FIG. **3** is a diagram illustrating an example of a pattern image projected by a projection unit of the image correction system according to the first embodiment;

FIG. **4** is a diagram illustrating an example of non-linear distortion in a projected image projected by the projection unit of the image correction system according to the first embodiment;

FIG. **5** is a diagram illustrating an example of a case in which linear distortion and non-linear distortion are contained in a captured image captured by an image-capturing unit of the image correction system according to the first embodiment;

FIG. **6** is a diagram illustrating an example of a projected image after correction projected by the projection unit of the image correction system according to the first embodiment;

FIG. **7** is a diagram illustrating an example of functional blocks in a first correction unit of the image correction system according to the first embodiment;

FIG. **8** is a diagram illustrating an example of tilt, relative to a projection surface, of the image-capturing unit of the image correction system according to the first embodiment;

FIG. **9** is a diagram for explaining an example of a calculation method of a projection transformation matrix calculated by a projection transformation matrix calculation unit of the image correction system according to the first embodiment;

FIG. **10** is a flowchart for explaining an example of a generation method of a corrected image by the image correction system according to the first embodiment;

FIG. **11** is a diagram illustrating an example of functional blocks in a second correction unit of the image correction system according to the first embodiment;

FIG. **12** is a diagram for explaining an example of a correction method used in the second correction unit of the image correction system according to the first embodiment;

FIG. **13** is a diagram illustrating an example of relations among projection transformation matrices that correspond to projection, image-capturing, and correction by the image correction system according to the first embodiment;

FIG. **14** is a flowchart for explaining an example of a correction method used in the second correction unit of the image correction system according to the first embodiment;

FIG. **15** is a diagram for explaining an operation of the image correction system according to the first embodiment;

FIG. **16** is a diagram illustrating a first modification of the pattern image projected by the projection unit of the image correction system according to the first embodiment;

FIG. **17** is a diagram illustrating a second modification of the pattern image projected by the projection unit of the image correction system according to the first embodiment;

FIG. **18** is a block diagram illustrating an example of a configuration of functional blocks in an image correction system according to a second embodiment;

FIG. **19** is a diagram illustrating an example of a subject of an image-capturing apparatus of the image correction system according to the second embodiment;

FIG. **20** is a block diagram illustrating an example of a configuration of functional blocks in an image correction system according to a third embodiment;

FIG. **21** a diagram illustrating an example of a subject of an image-capturing apparatus of the image correction system according to the third embodiment;

FIG. **22** is a diagram illustrating an example of a subject of the image-capturing apparatus of the image correction system according to the third embodiment; and

FIG. **23** is a diagram for explaining an example of a hardware configuration to execute software (computer program) in the image correction systems according to the first to the third embodiments.

BEST MODES FOR CARRYING OUT THE INVENTION

Embodiments will now be described in detail below of an image correction system, an image correction method and a computer program product with reference to the accompanying drawings.

First Embodiment

FIG. **1** is a block diagram illustrating an example of a configuration of functional blocks in an image correction system **1** according to a first embodiment. The image correction system **1** of the first embodiment includes an image-capturing apparatus **2** and a projection apparatus **3**. The image-capturing apparatus **2** includes an image-capturing unit **21** and a tilt recognition unit **22**. The projection apparatus **3** includes a controller **31**, a projection unit **32**, a first correction unit **33**, and a second correction unit **34**.

The image-capturing unit **21** captures a projected image projected by the projection unit **32**. The image-capturing unit **21** transmits the captured image to the first correction unit **33**.

The tilt recognition unit **22** recognizes tilt of an image-capturing direction of the image-capturing unit **21** relative to an image-capturing direction in which the image-capturing unit **21** being directly opposite to a projection surface captures the projection surface. The tilt recognition unit **22** recognizes the tilt with an accelerometer when the image-capturing unit **21** captures a projected image. The accelerometer, for example, provides such information as the image-capturing unit **21** is tilted by 10 degrees relative to the ground. The tilt recognition unit **22** transmits information indicating the tilt (hereinafter referred to as "tilt information") to the first correction unit **33**.

The accelerometer will be described. When the accelerometer is a three-axis accelerometer, trapezoidal distortion (linear distortion) in the longitudinal direction in a captured image can be corrected. When the accelerometer is a four-axis to six-axis accelerometer, trapezoidal distortion (linear distortion) in the lateral direction can also be corrected, and correction of gyro-like spin is also possible.

In general, a projection surface such as a screen on which the projection unit **32** projects an image is perpendicular to the ground. This can lead to an assumption that, when an external camera (image-capturing apparatus **2**) is directly opposite to the projection surface, the external camera (image-capturing apparatus **2**) is perpendicular to the ground. Therefore, a corrected image acquired by correcting tilt of a captured image by using tilt information recognized at the tilt recognition unit **22** is identical to a captured image (a captured image captured from the front) that is acquired when the external camera being directly opposite to the projection surface captures the projection surface such as a screen.

The image-capturing apparatus **2** may transmit a captured image and tilt information to the projection apparatus **3** in either of a wireless or wired manner.

The controller **31** inputs, into the projection unit **32**, an input image to be projected by the projection unit **32** as a projected image. The controller **31** also inputs the input image into the second correction unit **34** in order to correct non-linear distortion in the input image. The controller **31** receives, from the second correction unit **34**, a corrected input image that is generated by correcting the non-linear distortion in the input image. The controller **31** then inputs the corrected input image into the projection unit **32**.

The projection unit **32** projects the input image or the corrected input image as a projected image on a projection surface. The projection surface is, for example, a screen, a wall or a white board. The input image and the corrected input image will be described later in detail.

The first correction unit **33** generates a corrected image from a captured image on the basis of tilt information. The first correction unit **33** transmits the corrected image to the second correction unit **34**. The first correction unit **33** will be described later in detail.

The second correction unit **34** corrects non-linear distortion in the input image on the basis of the corrected image, and generates a corrected input image. The second correction unit **34** will be described later in detail.

FIG. **2** is a diagram illustrating an example of an embodiment of the image correction system **1** according to the first embodiment. The image correction system **1** in FIG. **2** is implemented by an external camera (image-capturing apparatus **2**) and a short-throw projector (projection apparatus **3**). The short-throw projector (projection apparatus **3**) is projecting a pattern image for correcting distortion in a projected image on a screen (projection surface). Intersections of the lines contained in the pattern image in FIG. **2** are used by the second correction unit **34**, as corresponding points for associating a corrected image generated by the first correction unit **33** with an input image.

FIG. **3** is a diagram illustrating an example of a pattern image projected by the projection unit **32** of the image correction system **1** according to the first embodiment. FIG. **3** is an example of a pattern image with a grid pattern.

In the example of FIG. **2**, the short-throw projector (projection apparatus **3**) is projecting the pattern image. In the example of FIG. **2**, non-linear distortion occurs in the projected pattern image because of the distortion of the screen (projection surface). The second correction unit **34** corrects the non-linear distortion in the projected image by using the intersections of the lines contained in the grid pattern image as the corresponding points between a corrected image and an input image.

Described are an input image input by the controller **31** into the projection unit **32**, and distortion in a projected image. FIG. **4** is a diagram illustrating an example of non-linear distortion in a projected image projected by the projection unit **32** of the image correction system **1** according to the first embodiment. The example of FIG. **4** illustrates a case in which a square is projected on the projection surface. In the example of FIG. **4**, non-linear distortion occurs in the square of the projected image because of the distortion of the projection surface.

When the image-capturing unit **21** acquires a captured image to detect this non-linear distortion, there is a case in which linear distortion occurs in the captured image because the image-capturing unit **21** deviates from a position directly opposite to the projection surface.

FIG. **5** is a diagram illustrating an example of a case in which linear distortion and non-linear distortion are contained in a captured image captured by the image-capturing unit **21** of the image correction system **1** according to the first embodiment. The example of the captured image in FIG. **5** is acquired, for example, when the external camera (image-capturing apparatus **2**) rotates horizontally to the ground in the right direction about the y-axis of the coordinate axes of the external camera (image-capturing apparatus **2**) in FIG. **2**, and deviates from a position directly opposite to the screen (projection surface).

The first correction unit **33** corrects a captured image containing linear distortion and non-linear distortion as illustrated in FIG. **5** by eliminating the linear distortion due to deviation of the image-capturing unit **21** from a position directly opposite to the projection surface, and generates a corrected image from the captured image.

FIG. **6** is a diagram illustrating an example of a projected image after correction projected by the projection unit **32** of the image correction system **1** according to the first embodiment. The second correction unit **34** generates a corrected input image on the basis of the input image and the corrected image generated by the first correction unit **33** from the captured image. When the projection unit **32** projects the corrected input image, a projected image after correction is displayed on the projection surface. The projected image after correction is identical to the input image.

Next, described in detail is the first correction unit **33** in the image correction system **1** according to the first embodiment. FIG. **7** is a diagram illustrating an example of functional blocks in the first correction unit **33** of the image correction system **1** of the first embodiment. The first correction unit **33** includes an intrinsic parameter matrix calculation unit **331**, a rotation matrix calculation unit **332**, a three-dimensional coordinate calculation unit **333**, a projection transformation matrix calculation unit **334**, and a corrected image generation unit **335**.

The intrinsic parameter matrix calculation unit **331** calculates an intrinsic parameter matrix of the image-capturing unit **21**. First, the intrinsic parameter matrix is described.

[Math. 1]

$$A = \begin{pmatrix} f & 0 & cx \\ 0 & f & cy \\ 0 & 0 & 1 \end{pmatrix} \quad (1)$$

Formula 1 is an intrinsic parameter matrix A. Described are components of the intrinsic parameter matrix A of Formula 1, where f denotes the focal length of the image-capturing unit **21**, cx denotes x-coordinate of the principal point (cx, cy) of the image-capturing unit **21**, and cy denotes y-coordinate of the principal point (cx, cy) of the image-capturing unit **21**.

The intrinsic parameter matrix calculation unit **331** needs to acquire the focal length f and the principal point (cx, cy) of the image-capturing unit **21** in order to calculate the intrinsic parameter matrix A.

The intrinsic parameter matrix calculation unit **331** may acquire the focal length f and the principal point (cx, cy) on the basis of exchangeable image file format (Exif) information that is tag information of a captured image. The intrinsic parameter matrix calculation unit **331** may acquire the focal length f and the principal point (cx, cy) by camera calibration of the image-capturing unit **21**.

The intrinsic parameter matrix A is used when the three-dimensional coordinate calculation unit **333** calculates, from two-dimensional coordinates of the captured image, three-dimensional coordinates in the real space corresponding to the two-dimensional coordinates.

The rotation matrix calculation unit **332** acquires tilt information from the tilt recognition unit **22**. The tilt information includes information indicating a tilt θ of an image-capturing direction of the image-capturing unit **21** relative to an image-capturing direction in which the image-capturing unit **21** being directly opposite to the projection surface captures the projection surface. The rotation matrix calcu-

lation unit **332** calculates a rotation matrix R representing coordinate transformation that rotates coordinates by just the tilt θ.

The rotation matrix R will now be described. FIG. **8** is a diagram illustrating an example of the tilt θ, relative to the projection surface, of the image-capturing unit **21** of the image correction system **1** according to the first embodiment. The example of FIG. **8** illustrates a case in which an image-capturing direction (z-axis direction) of the image-capturing apparatus **2** is rotated by just the tilt θ around the x-axis so that the image-capturing unit **21** is directly opposite to the projection surface. In FIG. **8**, x, y_1, and z_1 denote the coordinate axes before rotation by just the tilt θ, and x, y_2, and z_2 denote the coordinate axes after rotation by just the tilt θ.

Coordinates (x, y_2, z_2) can be calculated from the following formula by using the rotation matrix R that represents rotation by just the tilt θ.

[Math. 2]

$$\begin{pmatrix} x \\ y_2 \\ z_2 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} x \\ y_1 \\ z_1 \end{pmatrix} \quad (2)$$

The rotation matrix calculation unit **332** calculates a matrix that satisfies Formula 2 as the rotation matrix R.

The three-dimensional coordinate calculation unit **333** calculates three-dimensional coordinates corresponding to coordinates of a captured image by perspective projection transformation in which the coordinates of the captured image and the intrinsic parameter matrix A of the image-capturing unit **21** are used. Perspective projection transformation will now be described. Capturing a projected image by the image-capturing unit **21** corresponds to an operation of transforming the three-dimensional coordinates in the real space into the two-dimensional coordinates in the captured image. This transformation is called perspective projection transformation. Perspective projection transformation can be represented by a perspective projection transformation matrix P of the image-capturing unit **21**. The perspective projection transformation matrix P is expressed by the following formula.

[Math. 3]

$$P = A[Rt] = \begin{pmatrix} f & 0 & cx \\ 0 & f & cy \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{pmatrix} \quad (3)$$

The matrix A in Formula 3 is the above-mentioned intrinsic parameter matrix of the image-capturing unit **21**. A matrix [Rt] is an extrinsic parameter matrix. The extrinsic parameter matrix represents rotation and translation of the image-capturing unit **21**.

When the image-capturing unit **21** is tilted by just the tilt θ as illustrated in FIG. **8** and captures a projected image, a perspective projection transformation matrix P_1 is expressed by the following formula.

[Math. 4]

$$P_1 = \begin{pmatrix} f & 0 & cx \\ 0 & f & cy \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \end{pmatrix} \quad (4)$$

Formula 4 defines t=0 because the image-capturing unit **21** itself is the origin, and because the image-capturing unit **21** rotates about the origin.

The relation between the three-dimensional coordinates in the real space and the two-dimensional coordinates in the captured image can be represented as follows.

[Math. 5]

$$\begin{pmatrix} x_p \\ y_p \\ 1 \end{pmatrix} \cong \begin{pmatrix} f & 0 & cx \\ 0 & f & cy \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta & 0 \\ 0 & \sin\theta & \cos\theta & 0 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \quad (5)$$

Formula 5 represents equality except for scale. That is, Formula 5 represents equality in a homogeneous coordinate system.

When the image-capturing unit **21** being directly opposite to the projection surface captures the projection surface, a perspective projection transformation matrix P_2 is expressed by the following formula.

[Math. 6]

$$P_2 = \begin{pmatrix} f & 0 & cx \\ 0 & f & cy \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \quad (6)$$

The relation between the three-dimensional coordinates in the real space and the two-dimensional coordinates in the captured image can be represented as follows.

[Math. 7]

$$\begin{pmatrix} x_1 \\ y_1 \\ 1 \end{pmatrix} \cong \begin{pmatrix} f & 0 & cx \\ 0 & f & cy \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \quad (7)$$

In general, Formula 7 is equivalent to Formula 8 below. In Formula 7, R is defined as the identity matrix, and t is defined as 0. Thus, Formula 8 below defines R=E (identity matrix) and t=0.

[Math. 8]

$$\begin{cases} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = R \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + t \\ x' = x/z \\ y' = y/z \\ x_1 = f * x' + cx \\ y_1 = f * y' + cy \end{cases} \quad (8)$$

The three-dimensional coordinate calculation unit **333** calculates three-dimensional coordinates in the real space corresponding to the coordinates of the captured image by using an inverse transformation matrix P_1^{-1} that is the inverse of the perspective projection transformation matrix P_1. The three-dimensional coordinate calculation unit **333** does not need to calculate the corresponding three-dimensional coordinates in the real space with respect to all the points in the two-dimensional coordinates of the captured image. In other words, the three-dimensional coordinate calculation unit **333** may calculate corresponding points in the three-dimensional coordinates corresponding to the points in the captured image as many a number as needed (four) to calculate a projection transformation matrix H to be described later.

The projection transformation matrix calculation unit **334** calculates the projection transformation matrix H that transforms the coordinates of the captured image into coordinates of the corrected image. The projection transformation matrix H is used by the corrected image generation unit **335** to calculate the coordinates of the corrected image corresponding to the coordinates of the captured image.

FIG. **9** is a diagram for explaining an example of a calculation method of the projection transformation matrix H calculated by the projection transformation matrix calculation unit **334** of the image correction system **1** according to the first embodiment. The projection transformation matrix H is expressed by the following formula.

[Math. 9]

$$p_2 \cong Hp_1 \tag{9}$$

[Math. 10]

$$\begin{pmatrix} x_2 \\ y_2 \\ 1 \end{pmatrix} \cong \begin{pmatrix} h_1 & h_2 & h_3 \\ h_4 & h_5 & h_6 \\ h_7 & h_8 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \\ 1 \end{pmatrix} \tag{10}$$

Formula 9 and Formula 10 represent equality except for scale. That is, Formula 9 and Formula 10 represent equality in a homogeneous coordinate system.

Calculating coefficients of the projection transformation matrix H results in calculating Formula 11 below.

[Math. 11]

$$\begin{cases} x_2 = \dfrac{h_1 x_1 + h_2 y_1 + h_3}{h_7 x_1 + h_8 y_1 + 1} \\ y_2 = \dfrac{h_4 x_1 + h_5 y_1 + h_6}{h_7 x_1 + h_8 y_1 + 1} \end{cases} \tag{11}$$

Formula 11 includes eight unknown coefficients h_1 to h_8. Formula 11 is obtained for each pair of coordinates (x_1, y_1) of the captured image and coordinates (x_2, y_2) of the corrected image corresponding to the coordinates (x_1, y_1) of the captured image. In order to determine the eight unknown coefficients h_1 to h_8, information on at least four points of the corresponding points in the corrected image corresponding to the points in the captured image. The coordinates (x_2, y_2) of the corrected image corresponding to the coordinates (x_1, y_1) of the captured image can be calculated by applying the perspective projection transformation matrix P_2 to the three-dimensional coordinates in the real space corresponding to the above-described coordinates of the captured image.

The projection transformation matrix calculation unit **334** may calculate the projection transformation matrix H by the least-square method that uses a plurality of pieces of information on the corresponding points in the corrected image corresponding to the points in the captured image. Thereby, if the above-described corresponding points acquired by the perspective projection transformation matrix calculation unit **334** contain some errors with respect to correspondence, a projection transformation matrix H can be calculated that contains minimum errors. The least-square method is not the only method for reducing the effect of errors with respect to correspondence, and other methods can be used for this purpose.

The corrected image generation unit **335** generates a corrected image by applying the projection transformation matrix H to all the pixel coordinates in the captured image.

FIG. **10** is a flowchart for explaining an example of a generation method of the corrected image by the image correction system **1** according to the first embodiment.

The first correction unit **33** receives a captured image from the image-capturing unit **21**. The first correction unit **33** also receives tilt information from the tilt recognition unit **22** (Step S**1**). The intrinsic parameter matrix calculation unit **331** calculates an intrinsic parameter matrix A of the image-capturing unit **21** on the basis of Exif information that is tag information of the captured image (Step S**2**). The rotation matrix calculation unit **332** calculates a rotation matrix R on the basis of the tilt information (Step S**3**).

The three-dimensional coordinate calculation unit **333** calculates a perspective projection transformation matrix P_1 from the intrinsic parameter matrix A of the image-capturing unit **21** and the rotation matrix R. The three-dimensional coordinate calculation unit **333** calculates three-dimensional coordinates corresponding to coordinates of the captured image by applying an inverse transformation matrix P_1^{-1} that is the inverse of the perspective projection transformation matrix P_1 to the coordinates of the captured image (Step S**4**). The projection transformation matrix calculation unit **334** calculates coordinates of a corrected image corresponding to the three-dimensional coordinates by applying a perspective projection transformation matrix P_2 to the three-dimensional coordinates (Step S**5**).

At Step S**4** and Step S**5**, the first correction unit **33** calculates corresponding points of the coordinates in the corrected image corresponding to points of the coordinates in the captured image. The projection transformation matrix calculation unit **334** calculates a projection transformation matrix H by the least-square method, in which the corresponding points of the coordinates in the corrected image corresponding to the points of the coordinates in the captured image is used (Step S**6**). The corrected image generation unit **335** generates the corrected image by applying the projection transformation matrix H to all the pixel coordinates in the captured image (Step S**7**).

Next, described is the second correction unit **34** in the image correction system **1** according to the first embodiment. FIG. **11** is a diagram illustrating an example of functional blocks in the second correction unit **34** of the image correction system **1** of the first embodiment. The second correction unit **34** includes a correction region determination unit **341**, a corresponding point detection unit **342**, a projection transformation matrix calculation unit **343**, and a corrected input image generation unit **344**.

The correction region determination unit **341** determines a correction region in the corrected image. FIG. **12** is a

diagram for explaining an example of a correction method used in the second correction unit **34** of the image correction system **1** according to the first embodiment. A region **41** in FIG. **12** is an example of the correction region determined by the correction region determination unit **341**. The correction region determination unit **341** may determine the region **41** by any method. For example, the correction region determination unit **341** determines, as the correction region, a rectangle having the equal aspect ratio to that of the projection region of the projected image.

Pixel values of an input image are associated with pixel values of the correction region. In general, a correction region is smaller than an input image in size. Thus, the input image needs to be reduced so that the input image is fully displayed on the correction region.

Back to FIG. **11**, the corresponding point detection unit **342** detects corresponding points in the pattern image on a corrected input image corresponding to points in a pattern image on the corrected image. For example, in the example of FIG. **12**, the corresponding point detection unit **342** associates a point **43** in the corrected image with a point **53** in the corrected input image. The corresponding point detection unit **342** associates a point **44** in the corrected image with a point **54** in the corrected input image. The corresponding point detection unit **342** associates a point **45** in the corrected image with a point **55** in the corrected input image. The corresponding point detection unit **342** associates a point **46** in the corrected image with a point **56** in the corrected input image. Thereby, a unit region **42** in the corrected image is associated with a unit region **52** in the corrected input image.

The projection transformation matrix calculation unit **343** determines a projection transformation matrix H_n' for each unit region n. For example, the projection transformation matrix calculation unit **343** determines the projection transformation matrix H_n' on the basis of Formula 11 obtained by four points detected by the corresponding point detection unit **342**.

The corrected input image generation unit **344** determines pixel values of coordinates obtained by applying the projection transformation matrix H_n' to coordinates in the correction region on the basis of pixel values of the coordinates in the correction region to which the projection transformation matrix H_n' is applied. The pixel values are not based on pixel values of the correction region in the corrected image but on pixel values of the input image fitted to the region **41**.

For example, the corrected input image generation unit **344** determines a pixel value **57** of the corrected input image on the basis of a pixel value **47** of the input image in a position corresponding to a position in the correction region associated by the projection transformation matrix H_1'. The corrected input image generation unit **344** determines a pixel value of a certain point in the corrected input image by the projection transformation matrix H_n'. Thereby, the corrected input image generation unit **344** generates a corrected input image **51**.

FIG. **13** is a diagram illustrating an example of relations among projection transformation matrices that correspond to projection, image-capturing, and correction by the image correction system **1** according to the first embodiment. Projecting an input image by the projection unit **32** corresponds to the transformation represented by an inverse matrix $(H_n')^{-2}$ that is the inverse of the projection transformation matrix H_n'. Capturing a projected image corresponds to the transformation represented by the inverse matrix H^{-1} that is the inverse of the projection transformation matrix H calculated by the first correction unit **33**. Therefore, the projected image and the corrected image are identical. That is, a matrix E is the identity matrix.

The second correction unit **34** transforms coordinates of the correction region in the corrected image into coordinates of the corrected input image by the projection transformation matrix H_n'. The second correction unit **34** determines pixel values of the coordinates in the corrected input image to be the same pixel values as those in the input image that has been fitted to the correction region. Thus, an image in the correction region and a projected image after correction are identical. That is, a matrix E_n is the identity matrix.

FIG. **14** is a flowchart for explaining an example of a correction method used in the second correction unit **34** of the image correction system **1** according to the first embodiment.

The corresponding point detection unit **342** calculates corresponding points between a corrected image and a corrected input image by using grid points in the grid pattern image (Step S**11**). This associates unit regions in the corrected image with unit regions in the corrected input image. The correction region determination unit **341** determines a correction region to be corrected by the second correction unit **34** (Step S**12**). The correction region determination unit **341** associates pixel values of the input image with pixel values of the correction region (Step S**13**). The projection transformation matrix calculation unit **343** calculates projection transformation matrices for respective unit regions in the correction region (Step S**14**). The corrected input image generation unit **344** transforms certain coordinates in the correction region in the corrected image into coordinates of the corrected input image by the projection transformation matrix H_n'. The corrected input image generation unit **344** generates the corrected input image by determining pixel values of the coordinates in the corrected input image to be the same pixel values as those in the input image that has been fitted to the correction region (Step S**15**).

FIG. **15** is a diagram for explaining an operation of the image correction system **1** according to the first embodiment.

The controller **31** transmits to the projection unit **32** a signal indicating the start of calibration of a projected image (Step S**21**). The projection unit **32** projects a pattern image as the projected image on a projection surface (Step S**22**). The image-capturing unit **21** captures the projected image and acquires a captured image (Step S**23**). The tilt recognition unit **22** recognizes a tilt θ of the image-capturing unit **21** at the time of capturing at Step S**23** (Step S**24**). The first correction unit **33** generates a corrected image by correcting the captured image on the basis of an intrinsic parameter matrix of the image-capturing unit **21** and the tilt θ recognized at the time of capturing (Step S**25**).

The second correction unit **34** calculates, as distortion correction parameters, a correction region in the corrected image, and a projection transformation matrix calculated for each unit region and used for transforming a corrected image into a corrected input image (Step S**26**). The following describes S**26** in detail. First, the correction region in the corrected image is described. The correction region in the corrected image will be a projection region in a corrected projected image. Thus, the second correction unit **34** determines an aspect ratio of the correction region to be equal to that of an input image. In general, a corrected projected image (corrected input image) projected on a projection surface corresponding to a correction region in a corrected image is a reduced input image.

Next, described is the projection transformation matrix calculated for each unit region and used for transforming a corrected image into a corrected input image. The second correction unit **34** detects corresponding points between a pattern image on the corrected image and that on the input image. The second correction unit **34** calculates a projection transformation matrix for each unit region defined by line segments joining the corresponding points.

The second correction unit **34** stores the distortion correction parameter into a memory of the image correction system **1** (Step S**27**). The second correction unit **34** receives an input image from the controller **31** (Step S**28**). The second correction unit **34** reads out the distortion correction parameter that has been stored at Step S**27** from the memory (Step S**29**). The second correction unit **34** corrects the input image on the basis of the distortion correction parameter (Step S**30**).

The controller **31** determines whether or not it has received a command that instructs termination of calibration of the projected image (Step S**31**). When the controller **31** receives a command that instructs termination of calibration (Yes at Step S**31**), the controller **31** terminates the process. When the controller **31** does not receive a command that instructs termination of calibration (No at Step S**31**), the process returns to Step S**28**.

The pattern image used in the image correction system **1** according to the first embodiment may be a pattern image other than the grid pattern image. FIG. **16** is a diagram illustrating a first modification of the pattern image projected, by the projection unit **32** of the image correction system **1** of the first embodiment. The example of FIG. **16** illustrates a pattern image of a chessboard pattern. FIG. **17** is a diagram illustrating a second modification of the pattern image projected by the projection unit **32** of the image correction system **1** of the first embodiment. The example of FIG. **17** illustrates a pattern image with circles.

The corresponding point detection unit **342** of the second correction unit **34** may detect corresponding points without using a pattern image. For example, the corresponding point detection unit **342** may apply, to a content image of a user, a corresponding-point extraction method in which scale invariant feature transform (SIFT) is used. When the controller **31** determines that the content image of a user has few image features, the controller **31** may determine not to apply the corresponding-point extraction method by SIFT to the content image. Specifically, the controller **31** may calculate frequencies of content images, and determine not to use a content image with few high-frequency components.

The correction processing by the first correction unit **33** and the second correction unit **34** may be performed in an external computer connected through a network instead of in the projection apparatus **3**. The image correction system **1** may be connected with the external computer in either of a wired or wireless manner.

Using an accelerometer is not the only method for the tilt recognition unit **22** to recognize tilt of the image-capturing apparatus **2**. For example, the tilt recognition unit **22** may recognize tilt of the image-capturing apparatus **2** on the basis of image processing in which a captured image captured by the image-capturing apparatus **2** is used. In the image processing, for example, the tilt recognition unit **22** may recognize the tilt of the image-capturing apparatus **2** by detecting an upper and a lower black edges of a projection surface (such as a screen) contained in a captured image, and using the ratio of the length of the upper black edge to that of the lower black edge.

Second Embodiment

Next, described is an image correction system **1** according to a second embodiment. FIG. **18** is a block diagram illustrating an example of a configuration of functional blocks in the image correction system **1** of the second embodiment. The image correction system **1** of the second embodiment differs from the image correction system **1** of the first embodiment in that the image-capturing apparatus **2** includes the first correction unit **33** and the second correction unit **34**. This allows the projection apparatus **3** to have a simple configuration that includes only basic functions for projection. The image correcting system **1** of the second embodiment also differs in that it includes a storage unit **23** that stores a corrected captured image acquired by correcting non-linear distortion in a corrected image by the second correction unit **34**. Detailed description of the operation of the image correction system **1** according to the second embodiment is omitted because the description thereof is the same as that of the operation of the image correction system **1** according to the first embodiment.

In the description of the image correction system **1** of the first embodiment, the projection apparatus **3** projects an image on a screen as a projection surface, and the image-capturing apparatus **2** captures the projection surface, for example. However, the projection surface for the projection apparatus **3** and the subject for the image-capturing apparatus **2** are not limited to a screen. In the description of the image correction system **1** of the second embodiment, described is a case in which the subject of the image-capturing apparatus **2** is not the screen.

FIG. **19** is a diagram illustrating an example of a subject of the image-capturing apparatus **2** of the image correction system **1** according to the second embodiment. The example of FIG. **19** illustrates a case in which the projection apparatus **3** projects the pattern image with circles illustrated in FIG. **17** on a book, and the image-capturing apparatus **2** acquires a captured image by capturing the book. Following description is a case of correcting a captured image acquired by capturing a book. First, the image-capturing unit **21** acquires a captured image by capturing a book on which a pattern image is projected. Then, the first correction unit **33** acquires a corrected image by correcting trapezoidal distortion (linear distortion) in the captured image because of the image-capturing apparatus **2** not being directly opposite to the book as the subject when capturing it.

Next, the second correction unit **34** acquires a corrected captured image by correcting non-linear distortion caused by, for example, a bend in the book. Specifically, the second correction unit **34** receives the pattern image illustrated in FIG. **17** as an input image, and calculates the above-described projection transformation matrix H_n' from the input image and the corrected image. In other words, the second correction unit **34** calculates the above-described projection transformation matrix H_n' by establishing correspondences between the circles in the pattern image illustrated in FIG. **17** and the circles in the pattern image contained in the corrected image. The pattern image projected by the projection unit **32** is not limited to the pattern image illustrated in FIG. **17**, but any pattern image can be used in order for the second correction unit **34** to calculate the projection transformation matrix H_n'. The second correction unit **34** stores projection transformation matrices H_n' for respective regions n (regions including respective circles in the pattern image) in the storage unit **23**. Thereby, the second correction unit **34** can correct non-linear distortion identical to the non-linear distortion caused by, for example,

a bend in the book illustrated in FIG. **19**. For example, the projection transformation matrices H_n' stored in the storage unit **23** can be used in a case in which the subject is a book that has the same shape as that of the book in FIG. **19** and on which the same non-linear distortion occurs as that on the book in FIG. **19**.

The second correction unit **34** acquires a corrected captured image by transforming the respective regions n in the corrected image by the projection transformation matrices H_n', and stores the corrected captured image in the storage unit **23**. The image-capturing apparatus **2** may transmits the corrected captured image to the projection apparatus **3**, and then the projection apparatus **3** may project the corrected captured image. Thereby, when a book is captured as a subject to acquire a captured image, and then the first correction unit **33** and the second correction unit **34** correct the captured image to acquire a corrected captured image, the corrected captured image can be displayed as a projected image on a projection surface such as a screen.

Third Embodiment

Next, described is an image correction system **1** according to a third embodiment. FIG. **20** is a block diagram illustrating an example of a configuration of functional blocks in the image correction system **1** of the third embodiment. The image correction system **1** of the third embodiment includes the image-capturing apparatus **2** and a display apparatus **4**. The image correction system **1** of the third embodiment differs from the image correction systems **1** of the first and the second embodiments in that it includes the display apparatus **4** instead of the projection apparatus **3**. The display apparatus **4** includes a display unit **5** that displays a corrected captured image.

The configuration of the image-capturing apparatus **2** of the image correction system **1** of the third embodiment is the same as that of the second embodiment, and thus the description thereof is omitted. The detailed description of the operation of the image correction system **1** of the third embodiment is also omitted because the description thereof is the same as that of the image correction systems **1** of the first and the second embodiments.

FIGS. **21** and **22** are diagrams each illustrating an example of a subject of the image-capturing apparatus **2** of the image correction system **1** according to the third embodiment. FIG. **21** is an example of a book containing pages on which a pattern image is printed. FIG. **22** is an example of a sheet of paper on which a pattern image is printed. Following description is an example of a case in which the subject of the image-capturing apparatus **2** is the book illustrated in FIG. **21**. It should be noted that the following description is also applicable to a case in which the subject of the image-capturing apparatus **2** is the sheet of paper illustrated in FIG. **22**.

First, the image-capturing unit **21** acquires a captured image by capturing a book on which a pattern image is printed. Then, the first correction unit **33** acquires a corrected image by correcting trapezoidal distortion (linear distortion) in the captured image because of the image-capturing apparatus **2** not being directly opposite to the book as the subject when capturing it. The second correction unit **34** reads out the same pattern image as the pattern image printed on the book from the storage unit **23**, and then calculates the above-described projection transformation matrix H_n' from the pattern image and the corrected image.

The second correction unit **34** stores, in the storage unit **23**, projection transformation matrices H_n' for respective regions n (regions including respective circles in the pattern image) in the corrected image. Thereby, the second correction unit **34** can correct non-linear distortion that is identical to the non-linear distortion caused by, for example, a bend in the book illustrated in FIG. **21**. The second correction unit **34** acquires a corrected captured image by transforming the respective regions n in the corrected image by the projection transformation matrices, H_n', and stores the corrected captured image in the storage unit **23**. The image-capturing apparatus **2** transmits the corrected captured image to the display apparatus **4** to display the corrected captured image on the display unit **5** of the display apparatus **4**. Thereby, when a book is captured as a subject to acquire a captured image, and the first correction unit **33** and the second correction unit **34** corrects the captured image to acquire a corrected captured image, the corrected captured image can be displayed on the display unit **5** of the display apparatus **4**.

The tilt recognition unit **22**, the controller **31**, the first correction unit **33**, and the second correction unit **34** of the image correction systems **1** according to the first to the third embodiments may be implemented either by hardware such as an integrated circuit (IC), or by software (computer program). The tilt recognition unit **22**, the controller **31**, the first correction unit **33**, and the second correction unit **34** of the image correction systems **1** of the first to the third embodiments may be implemented by combining hardware and software (computer program).

FIG. **23** is a diagram for explaining an example of a hardware configuration to execute software (computer program) in the image correction systems **1** according to the first to the third embodiments. The image-capturing apparatus **2** of the first to the third embodiments, and the projection apparatus **3** of the first and the second embodiments include an auxiliary memory **61** such as a memory card, a main memory **62** such as a random access memory (RAM), a processor **63** such as a central processing unit (CPU), and a communication interface (I/F) **64** for communicating with other apparatuses. The auxiliary memory **61**, the main memory **62**, the processor **63**, and the communication I/F **64** are connected one another through a bus **65**.

The auxiliary memory **61** stores software (computer program). However, the software (computer program) may be provided as a computer program product recorded in a file in an installable or executable format in a recording medium, such as a CD-ROM, a flexible disk (FD), a CD-R, and a digital versatile disk (DVD), that is readable by a computer.

The software (computer program) may be stored on a computer connected to a network such as the Internet, and may be provided by downloading through the network. The software (computer program) may also be provided or distributed through a network such as the Internet.

The processor **63** reads out the software (computer program) stored in the auxiliary memory **61** such as a memory card, a storage medium such as a CD-ROM, or a computer on a network to execute it on the main memory **62**. Thereby, when the tilt recognition unit **22**, the controller **31**, the first correction unit **33**, and the second correction unit **34** are implemented by software (computer program), these functional blocks are implemented on the main memory **62**.

INDUSTRIAL APPLICABILITY

The image correction systems **1** according to the first to the third embodiments can provide an image correction system, an image correction method and a computer program that can eliminate distortion in a subject contained in

a captured image by using the captured image even if the captured image acquired by the image-capturing apparatus **2** capturing the subject is distorted.

Although the invention has been described with respect to specific embodiments for a complete and clear disclosure, the appended claims are not to be thus limited but are to be construed as embodying all modifications and alternative constructions that may occur to one skilled in the art that fairly fall within the basic teaching herein set forth.

EXPLANATION OF LETTERS OR NUMERALS

1 Image correction system
2 Image-capturing apparatus
3 Projection apparatus
4 Display apparatus
5 Display unit
21 Image-capturing unit
22 Tilt recognition unit
23 Storage unit
31 Controller
32 Projection unit
33 First correction unit
34 Second correction unit
331 Intrinsic parameter matrix calculation unit
332 Rotation matrix calculation unit
333 Three-dimensional coordinate calculation unit
334 Projection transformation matrix calculation unit
335 Corrected image generation unit
341 Correction region determination unit
342 Corresponding point detection unit
343 Projection transformation matrix calculation unit
344 Corrected input image generation unit
61 Auxiliary memory
62 Main memory
63 Processor
64 Communication I/F
65 Bus
A Intrinsic parameter matrix
H Projection transformation matrix
H_1' Projection transformation matrix
H_n' Projection transformation matrix
P Perspective projection transformation matrix
P_1 Perspective projection transformation matrix
P_2 Perspective projection transformation matrix
R Rotation matrix
f Focal length
θ Tilt

The invention claimed is:

1. An image correction system comprising:
an image-capturing unit configured to acquire a captured image by capturing a subject;
a tilt recognition unit configured to recognize tilt of an image-capturing direction of the image-capturing unit relative to an image-capturing direction in which the image-capturing unit being directly opposite to the subject captures the subject;
a first correction unit configured to generate a corrected image by correcting distortion in the captured image on the basis of information indicating the tilt; and
a second correction unit configured to acquire a corrected captured image by correcting non-linear distortion in the corrected image,
wherein the tilt recognition unit recognizes the tilt with an accelerometer.

2. The image correction system according to claim **1**, wherein
the first correction unit comprises:
a projection transformation matrix calculation unit configured to calculate coordinates of the corrected image corresponding to coordinates of the captured image, and calculate a projection transformation matrix that transforms the coordinates of the captured image into the coordinates of the corrected image; and
a corrected image generation unit configured to generate the corrected image by applying the projection transformation matrix to coordinates of all pixels in the captured image.

3. The image correction system according to claim **2**, wherein
the first correction unit further comprises:
an intrinsic parameter matrix calculation unit configured to calculate an intrinsic parameter matrix of the image-capturing unit;
a rotation matrix calculation unit configured to calculate a rotation matrix representing coordinate transformation due to the tilt; and
a three-dimensional coordinate calculation unit configured to calculate three-dimensional coordinates corresponding to the coordinates of the captured image by perspective projection transformation in which the coordinates of the captured image, the intrinsic parameter matrix of the image-capturing unit, and the rotation matrix are used, and
the projection transformation matrix calculation unit calculates, from the three-dimensional coordinates, the coordinates of the corrected image corresponding to the coordinates of the captured image by perspective projection transformation in which the intrinsic parameter matrix is used.

4. The image correction system according to claim **1**, further comprising:
a projection unit configured to project an image on a projection surface, wherein
the image-capturing unit acquires a captured image by capturing the projected image as the subject;
the second correction unit acquires a corrected projected image by correcting non-linear distortion in the corrected image; and
the projection unit further projects the corrected projected image on the projection surface.

5. The image correction system according to claim **1**, wherein the tilt recognition unit recognizes the tilt when the image-capturing unit captures the subject.

6. An image correction method comprising:
acquiring, by an image-capturing unit, a captured image by capturing a subject;
recognizing, by a tilt recognition unit, tilt of an image-capturing direction of the image-capturing unit relative to an image-capturing direction in which the image-capturing unit being directly opposite to the subject captures the subject, the tilt recognition unit recognizing the tilt with an accelerometer;
generating, by a first correction unit, a corrected image by correcting distortion in the captured image on the basis of information indicating the tilt; and
acquiring, by a second correction unit, a corrected captured image by correcting non-linear distortion in the corrected image.

7. A computer program product comprising a non-transitory computer-usable medium having a computer program that causes a computer to function as:

an image-capturing unit configured to acquire a captured image by capturing a subject;

a tilt recognition unit configured to recognize tilt of an image-capturing direction of the image-capturing unit relative to an image-capturing direction in which the image-capturing unit being directly opposite to the subject captures the subject;

a first correction unit configured to generate a corrected image by correcting distortion in the captured image on the basis of information indicating the tilt; and

a second correction unit configured to acquire a corrected captured image by correcting non-linear distortion in the corrected image,

wherein the tilt recognition unit recognizes the tilt with an accelerometer.

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